DESIGN AND COST ESTIMATE OF A 25,000 K.V.A. GENERATING SYSTEM

BY

RICHARD J. GRANT

ARMOUR INSTITUTE OF TECHNOLOGY

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a 25,000 KVA generating

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DESIGN AND COST ESTIMATE OF A 25,000 K. V. A. GENERATING SYSTEM

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A THESIS

PRESENTED BY

RICHARD J. GRANT

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

JUNE 2, 1921

APPROVED

Professor of Electrical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

ILLINOIS INSTITUTE OF TECHNOLOGY
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This work has been done from the assumed viewpoint of a consulting engineer, to whom this project is brought for an estimate; he is given the complete design and data, as outlined below and in the accompanying blue prints; there are no outstanding data with the exception of the limitation of the period of construction to one year.

This preliminary estimate covers the total first cost of an electrical power system of 20,000 K. V. A. capacity, for supplying electric railway and lighting power at a power factor of 90% as shown on the load curve. The railway system is 100 miles long; the generating station and included substation is situated midway between the terminals; two substations are located near each end, 35 miles from the central station. Each substation has a normal capacity of 6,000 K. V. A. and its overload rating is sufficient to carry one third of the total peak load.

The central station consists of five, 5000 K. V. A., three-phase, 6000 volt, 60 cycle, turbo-generators, as shown on the blue print. Power is

29820

transmitted at 33,000 volts to each of the two isolated substations through two separate feeder lines, arranged along the right of way of the railroad. The equipment of each substation consists of two, 3,000 K. V. A., 3-phase, 60 cycle synchronous converters.

Blue prints are shown giving the details of wiring and construction.

This estimate has been made by methods conforming with the best practices in industrial engineering. The costs tabulated are mostly taken from prices quoted personally to the writer by the manufacturer; other costs, such as those of labor, installation and supervision have been carefully calculated from cost data of a few years ago as given in Gillette's Handbook of Cost Data and especially from Mechanical and Electrical Cost Data by Gillette and Dana. I have tried to conform throughout to sound economic and business principles, both as to choice of apparatus and as to the chronological order of the work.

EXCAVATION

The quantity of material to be excavated consists of 190'x 160' x 6' or 6750 cu. yards. of sand. The excavation goes down to bed rock, six feet below the surface. The steam shovel used is a 20-B whirly-type traction shovel, of $\frac{3}{4}$ cu. yd. capacity, capable of loading 300 cu. yards of sand per day under average conditions. The length of haul is 3 miles of city streets.

Labor:	1 foreman @ $1.25 / hr. for 22 days	$220.00
	10 laborers @ $1.00 / hr." " "	180.00
	Backfill and clean up @ $.05 / cu. yd	330.00
Mat. & Supplies	10 shovels @ $1.00 (see hand.)	10.00
	16 barrows @ $5.00 (" ")	80.00
Rents	Steam shovel for 22 days @ $100 / day	2200.00
	5 - 5-Ton Auto Trucks for 22 days @ $30 / day	3300.00
Interest	Int. on $6320 @ 6% for 1 year	380.00
Contingencies	5%	300.00
TOTAL		$7000.00
Per cu. yd.		$1.04
Per KW		.28

CONCRETE WORK

All concrete work is of 1-2½-5 mix. Foundations for main walls, main units to chimneys are six feet in depth (to bed-rock). The main walls are 20" in thickness and of a total volume of 420 cu. yds. The chimney foundations are of an average diam. of 16' and of a total volume of 90 cu. yds. The foundations for the turbo-generators are as shown in the plan and of a total volume of 155 cu. yds.; for the two rotary converters in the included substation, a total volume of 20 cu. yds. The floors of boiler room, and basement, turbine-room, and switch house are of a total volume of 950 cu. yds. Ground floors have a thickness of ½ foot, and all others 1 ft.

Total volume of concrete is 1630 cu. yds.

Form lumber is to be used four times and has a scrap value of 25%. Sand from excavation used for concrete.

Labor	Form work 64000 B.F. @ $.04 / B.F.	$2560.00
	Concrete work 1630 cu. yds. @ $2.00 / cu. yd.	3260.00
	Stripping and cleaning up @ $.008/B.F.	510.00
	Reinforcement placing @ $.50 / cu. yd.	460.00

Mat. &	16000 B. F. at $40 / M-scrap value	$ 480.00
Supplies	1950 bbl. of cement @ $3.60 /bbl.	7030.00
	1500 cu. yds. of stone @ $2.25/cu. yd.	3380.00
	Reinforcement steel 40 T. @ $55 / ton	2200.00
Rents	Mixer for 1 month.	100.00
Int.	Int. on $20000 for 11 mo. @ 6%	1100.00
Contingencies	15%	3200.00
Total		$24300.00
Per cu. Yd.		$ 14.90
Per K. W.		$ .97

ROOFING

Roofing is of standard fire-proof material such as Berger multiplex plate, and of a total area of 93000 sq. ft.

Labor	93000 sq. ft. @ $.24 / sq. ft.	$23300.00
Mat. & Supplies	93000 sq. ft. @ $.06 / sq. ft.	5600.00
Int.	$28900.00 for 8 mo. @ 6%	1150.00
Contin-gencies	10%	3000.00
Total		$33000.00
Per sq. ft.		$.355
Per K. W.		$1.32

MASONRY

The main walls are of 16" thickness with 28 bricks / sq. ft.; the switch house walls are of 12" thickness and 20 bricks / sq. ft. The average height of the walls is 60 feet, above grade. The number of bricks required is 2,000,000. Quantity of mortor required (1:3) is 1460 cu. yds.

Labor	Bricklaying @ $10.00 / M	$20000.00
	Laborers @ $8.00 / M	16000.00
Mat. & Supplies	Common brick @ $12.00 / M	18000.00
	Pressed " @ $24.00 / M	12000.00
	Lime (140 cu. yds.) @ $20.00 / ton	1600.00
	Cement (390 bbl) @ $3.60 / bbl.	1400.00
Int.	Int. on $69000.00 for 9 mo.@ 6%	3100.00
Contingencies	10%	7200.00
Total		$79300.00
Per K. W.		$3.13
Per 1000 bricks		$39.65

SUPERSTRUCTURE

This consists of a complete skeleton frame-work of steel, including wall girders, roof trusses, coal-hoppers and the necessary cross-bracing for the bldg. as shown in the drawing. The weight of structural steel required is 675 tons, including such sundries as rivets, bolts, plates, etc.

Labor	Erecting 675 tons of structural work @ $15.00 / ton	$10100.00
	Erecting 50-ton crane	500.00
	" 2 chimneys, 150 ft. high	3500.00
	Installing 55 windows @ $1.10 / window	600.00
	Laying 200 ft. R.R. track inside bldg.	200.00
Mat. & Supplies	675 tons of str. iron @$120.00/ton	81000.00
	50-ton crane	13500.00
	1 chimney 150' x 8'6"	16000.00
	1 " 150' x 10'	19000.00
	70 ties (creos) @ $2.20	150.00
	580 feet rails (80# yd.)	600.00
	Spikes, bolts, nuts, angles, etc.	500.00
	Bumper	50.00
	Windows, Doors	2000.00

Int.	Int. on $148000.00 @ 6% for 8 mo.	$ 6000.00
Contingencies & 10% Incidentals		15000.00
Total		$170000.00
Per K. W.		$6.80

SUMMARY OF COSTS OF BLDG. ALONE

Excav.	$ 7000.00
Concrete Work	24300.00
Masonry	79300.00
Skeleton Work	170000.00
Roofing	33000.00
Total	$313600.00
Per K. W.	$12.54

MACHINERY

All piping estimated for 250# pressure.

Labor	10-Boiler settings & installations	$ 75000.00
	5-Turbo-gen. installation	52500.00
	5-Condenser equipment installations	10500.00
	Piping work (steam, air, water.)	36000.00
	Installation of coal and ash handling mach.	25000.00
Mat. & Supplies	5-turbo-generators 5000 K. W.	500000.00
	5-Condenser Equipments	147000.00
	3125' Piping and covering complete	29000.00
	10-B.& W. 500 H.P. Boilers & Stokers	200000.00
	2-Boiler Feed Pumps	12500.00
	Coal and Ash Handling Mach.	12500.00
	Feed water heater	4000.00
Int. on Cap.	Int. on $1,104,000.00 @ 6% for 4 mo.	22080.00
Conting. & Incidentals	5%	5420.00

Total	$1,131,000.00
Per K. W.	$45.25

Note

Each condenser equipment consists of the following: 1-10000 sq. ft. surface condenser, 2-dry vacuum ejector pumps, 1-condensate pump, turbine-driven, and 1-circulating water pump, turbine-driven.

ELECTRICAL EQUIPMENT

The generated voltage is 6600. Each generator is excited from a 125 volt exciter bus. fed by a 225 K. W. D. C. generator. The transmission voltage is 33000. Both low and high tension busses are sectionalized. The neutral of each main unit is grounded. For further particulars, see Station Wiring Diagram and Switchboard.

Labor	Copper work	$ 27000.00
	Installing transformers	1000.00
	" switchboard	400.00
	" exciters	600.00
	" substation equipment	2000.00
Mat. & Supplies	See next Page	296580.00
Int. on Cap.	Int. on $327,500 @ 6% for 4 mo.	6500.00
Conting.	5%	16700.00
Total		$350000.00
Per K. W.		$14.00

MATERIAL AND SUPPLIES

Switchboard:	
5-Gen. Panels (Incl. all Switches)	$ 6000.00
4-Feeder Panel (6600 Volt)(")	2400.00
4- " " (3300 ")(")	9600.00
2-Exciter "	900.00
1-Lighting and Aux. Panel	950.00
1-Ground Detector	150.00
Transformers:	
13-Current Transformers	520.00
2-Potential "	160.00
15-Single-Phase 1667 K.V.A. (33000-6600)	75000.00
4-Three-Phase 3150 K. V. A. (" ")	84000.00
Exciters:	
1-Turbo-Generator (Incl. panel & switches)	9000.00
1-Motor-Generator (" " ")	7000.00
Substation equipment:	
2-3000 K.W. Syn. Converters	50000.00
2-Automatic Voltage Regulators	1100.00
2-Converter Switchboards (Incl. all switches)	15000.00
6-Single Phase	3000.00
4-Sets of Alum. Lgt. Arresters (Incl. choke coils etc.)	4800.00
Copper (incl. all insulation)	27000.00
Total	296580.00

TRANSMISSION SYSTEM

The transmission system consists of two sets of feeders or six wires to each substation. Each line is 35 mi. in length and consists of #4/0 copper wire mounted horizontally with four-foot spacing. The poles used are 35 feet in length spaced 200 ft. apart and guyed and anchored every half mile. This arrangement calls for 900 poles, 1000 cross-arms, 6000 insulators, 3500' of guy wire, 70 anchors and 210 mi. of wire per set of feeders.

Labor	900 poles @ $7.10	$ 6300.00
	1000 cross arms @ $.75	750.00
	6000 insulators @ $.05	300.00
	210 mi. of wire	5400.00
Mat. &	900 poles @ $20.00	18000.00
Supplies	1000 cross-arms @ $2.00	2000.00
	6000 insulators @ $.75	4500.00
	70 anchors @ $3.50	250.00
	3500' guy wire @ $.008	250.00
	822000# of wire @ $.24	206000.00
Int.	Int. on $243000 @ 6% for 4 mo.	4850.00

Contingencies	8%	$ 20000.00
Total		268500.00
Cost of complete transmission system		$537000.00

SUBSTATIONS

Each of the isolated substations is built similar to the included substation at the central station, so as to make for efficiency and economy in installation costs. The building is 30 ft. wide, 60 ft. long and 20 ft. high, of 12" brick wall, without windows; a saw-tooth roof provides the necessary lighting; a suitable ventilating system is installed, also, a 25-ton hand-operated crane of 30' span.

The quantity of material to be excavated is 30' x 60' x 6' or 400 cu. yds. The number of bricks required is approximately 72000. The amount of concrete required is: for wall foundations, 40 cu. yds; for machine foundations, 20 cu. yds; for main floor, 60 cu. yds.; for basement floor, 30 cu. yds.; making a total of 150 cu. yds. The steel required for the superstructure, including roof trusses, reinforcements, and bracing is 9 tons. The roofing surface is 5500 sq. ft. The substation equipment is as follows:

2-3000 K.W. synchronous converters & switchboards

2-33000 volt feeder panels

4-transformers (three-phase, 3150 K.V.A. 6600-33000)

2-automatic voltage regulators

2-converter switchboards.

Excavation:	
400 cu. yds. @ $1.04	$ 416.00
Concrete Work:	
150 cu. yds. @ $14.90	2215.00
Masonry:	
72 M bricks @ $39.65	2855.00
Superstructure:	
9 tons of steel @ $140.00	1260.00
Crane	2500.00
Roofing:	
5500 sq. ft. @ $.35	1930.00
Ventilating, Plumbing, Woodwork:	1200.00
Equipment:	
Material (as listed)	155000.00
Cost of installation	15500.00
Incidentals:	
Supervision, Painting, Contingencies	5000.00
Total	$188000.00
Per K. W.	$31.33
Cost of both substations	$376000.00

GENERAL EXPENSE

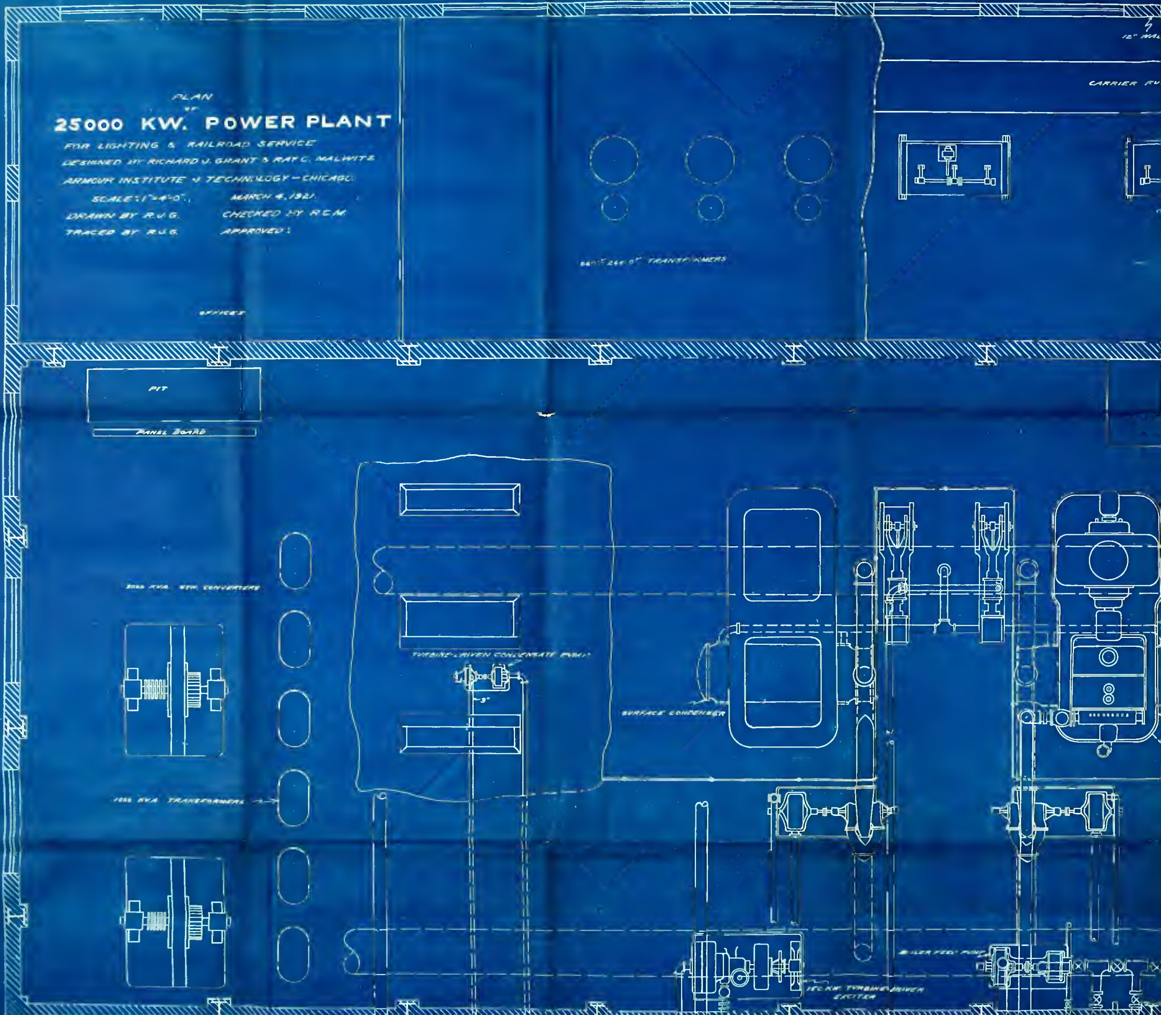
This item is estimated on the basis of percentage of total cost, assuming one year as the period of construction. Transportation is here taken into account by assuming the existance of a separate plant, maintained expressly for transportation purposes for one year.

Engineering and Superintendence	2.8%
Legal Expense	1.3%
Organization and Office Expense	2.0%
Insurance, Taxes, Damages, Right of Way	1.9%
Transportation Plant	1.0%
Total Overhead Charge	9%

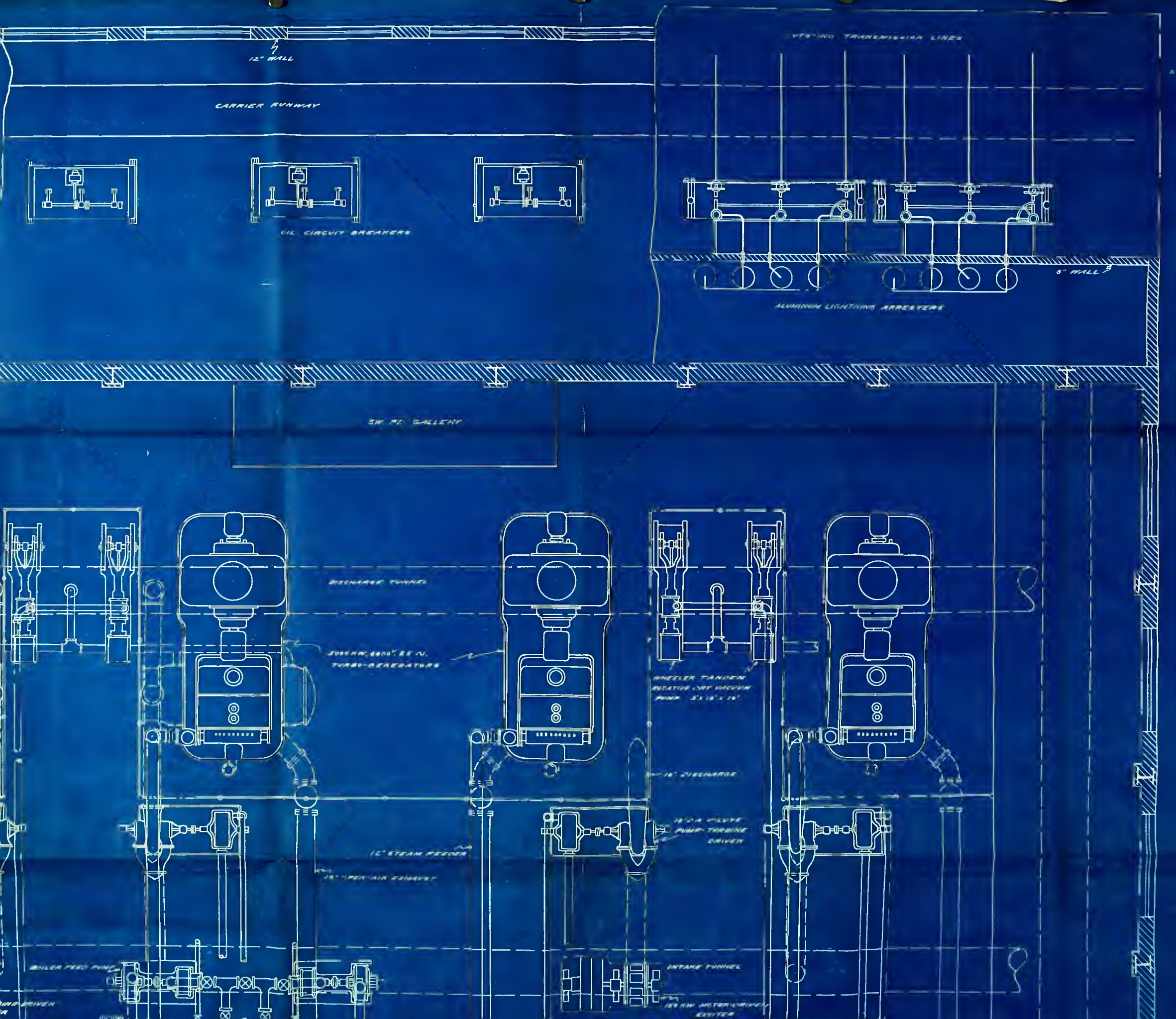
SUMMARY OF ESTIMATED COSTS

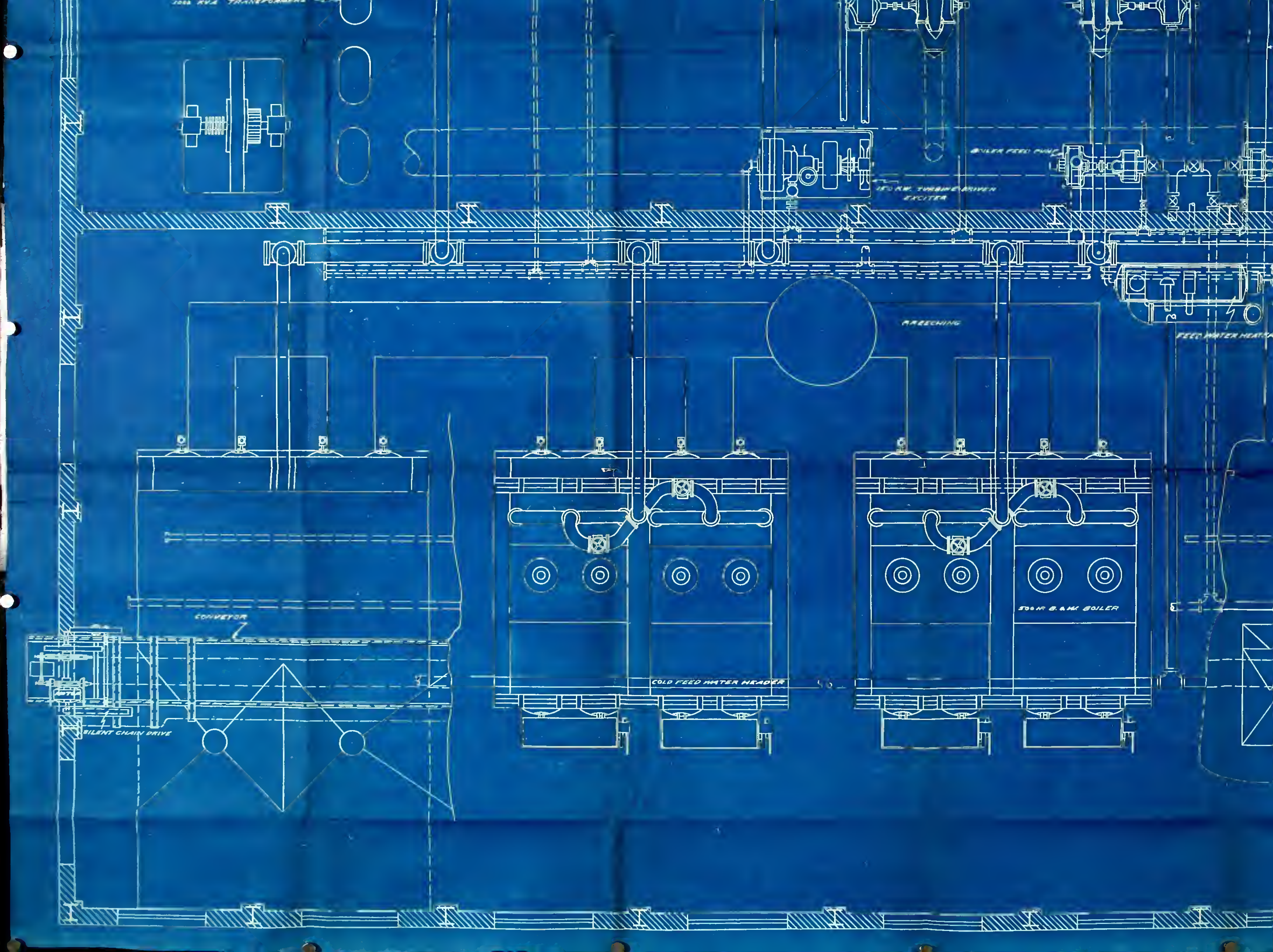
Main Building:	
Cost of bldg. proper	$ 313600.00
" " machinery	1131000.00
" " electrical equipment	350000.00
Substations:	
Cost of bldgs. and equipment	376000.00
Transmission System	537000.00
General Expense	222400.00
Total Cost of Generating and Transmission System	2695000.00

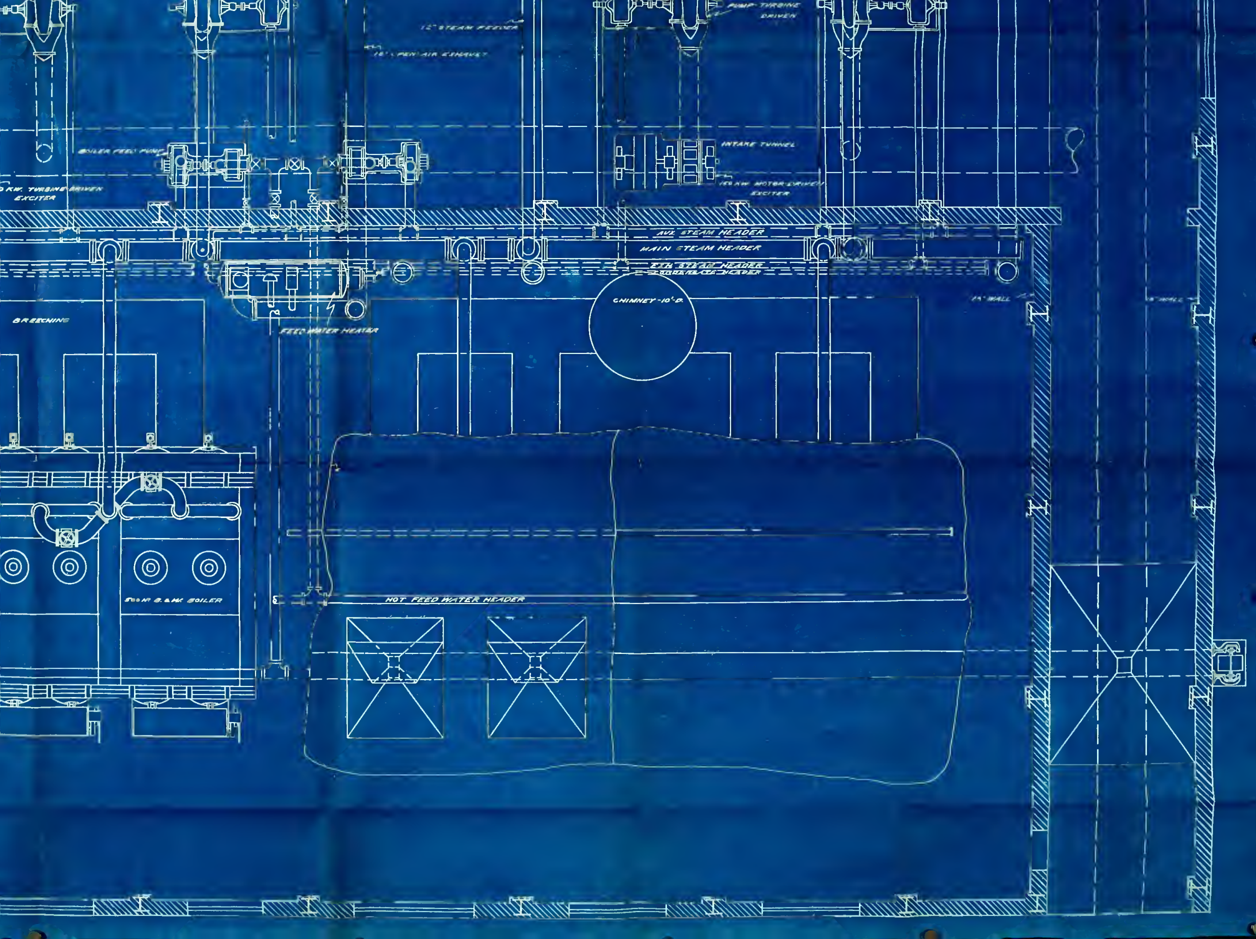
RJG:BG

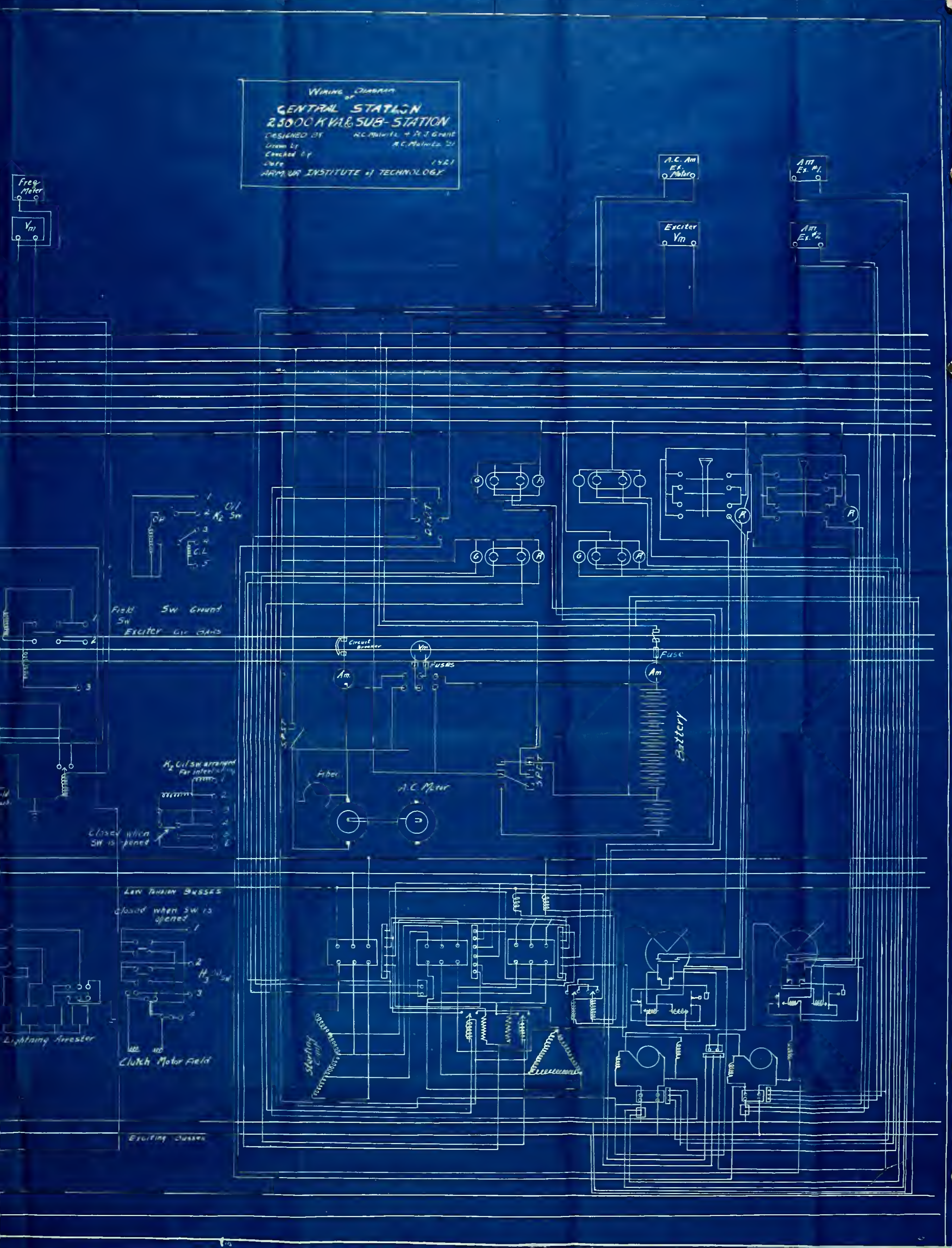


PLAN
OF
25000 KW. POWER PLANT
FOR LIGHTING & RAILROAD SERVICE
DESIGNED BY RICHARD J. GRANT & RAY C. MALWITZ
ARMOUR INSTITUTE OF TECHNOLOGY — CHICAGO.
SCALE: 1" = 4'-0".   MARCH 4, 1921.
DRAWN BY R.J.G.   CHECKED BY R.C.M.
TRACED BY R.J.G.   APPROVED:

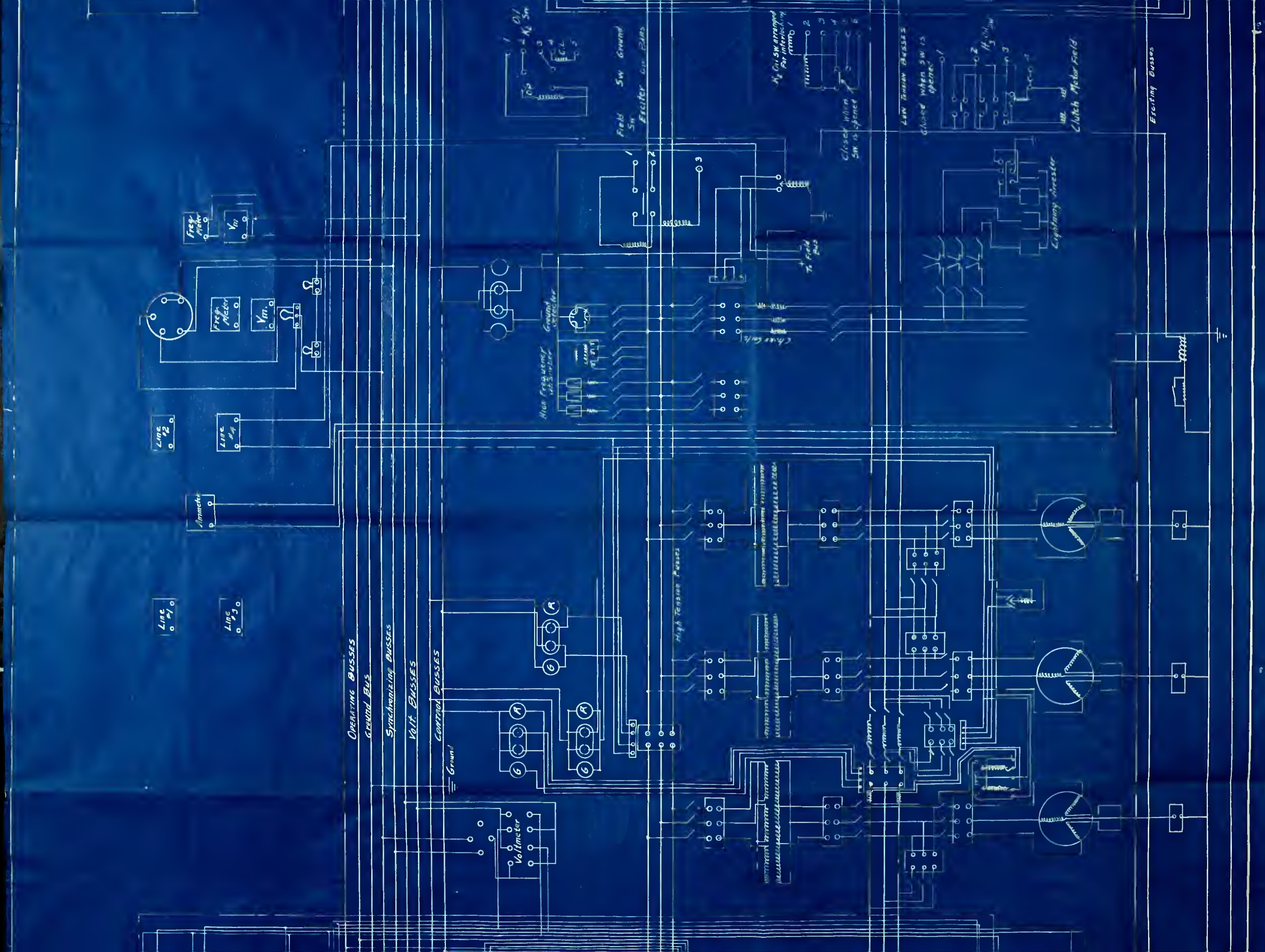

12" WALL
CARRIER RUNWAY
OIL CIRCUIT BREAKERS
OUTGOING TRANSMISSION LINES
8" WALL
ALUMINUM LIGHTNING ARRESTERS
SW. BD. GALLERY
DISCHARGE TUNNEL
3000 K.W., 6600 V. 25 ~.
TURBO-GENERATORS
WHEELER TANDEM
ROTATIVE DRY VACUUM
PUMP 3'x 12"x 18"
18" DISCHARGE
18" C.A. VOLUTE
PUMP-TURBINE
DRIVEN
12" STEAM FEEDER
18" OPEN-AIR EXHAUST
BOILER FEED PUMP
DRIVEN
INTAKE TUNNEL
150 KW MOTOR-DRIVEN
EXCITER

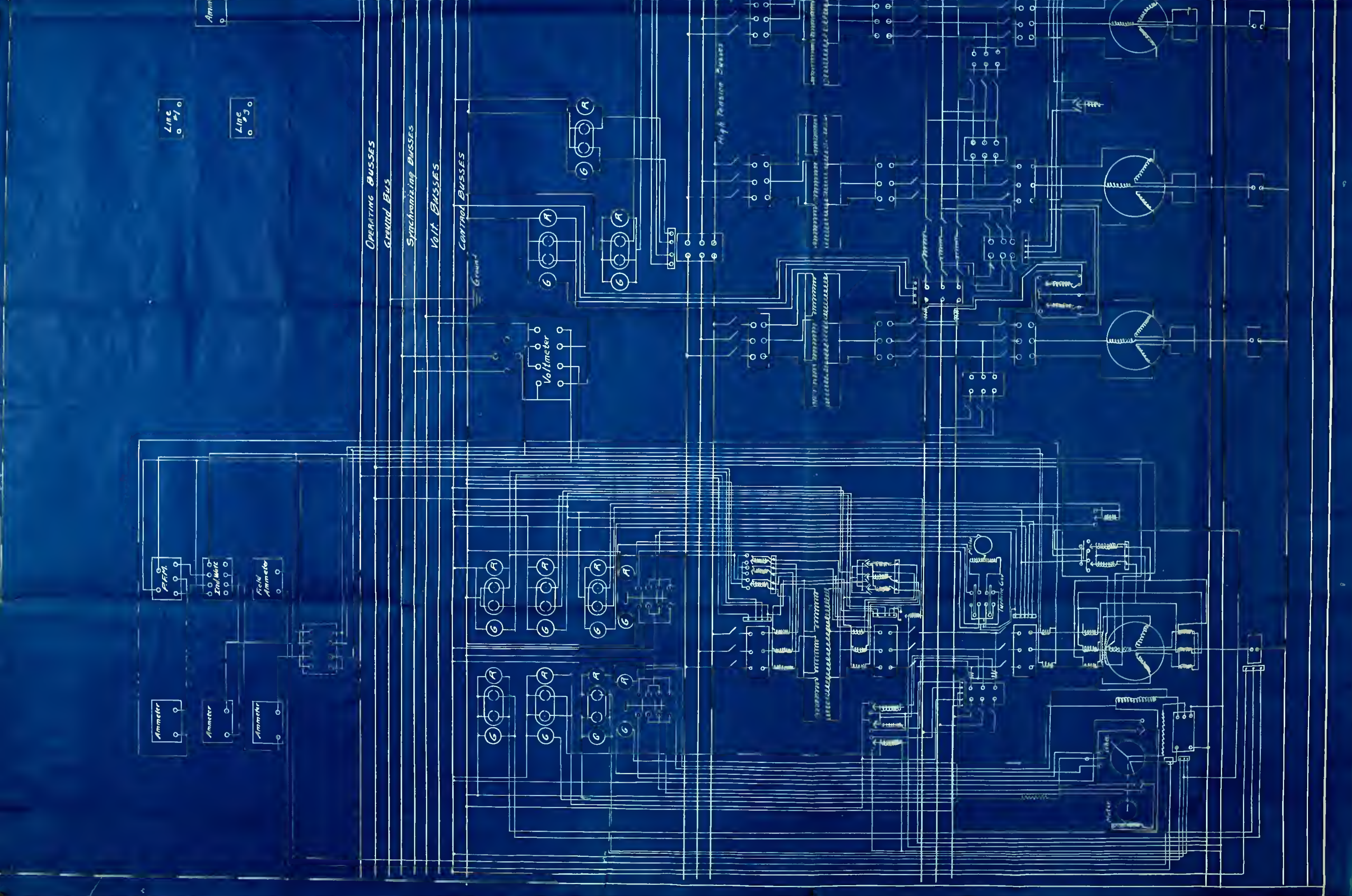

2000 KVA TRANSFORMERS
BOILER FEED PUMP
150 K.W. TURBINE DRIVEN EXCITER
BREECHING
FEED WATER HEATE
500 H.P. B.&W. BOILER
COLD FEED WATER HEADER
CONVEYOR
MOTOR
SILENT CHAIN DRIVE

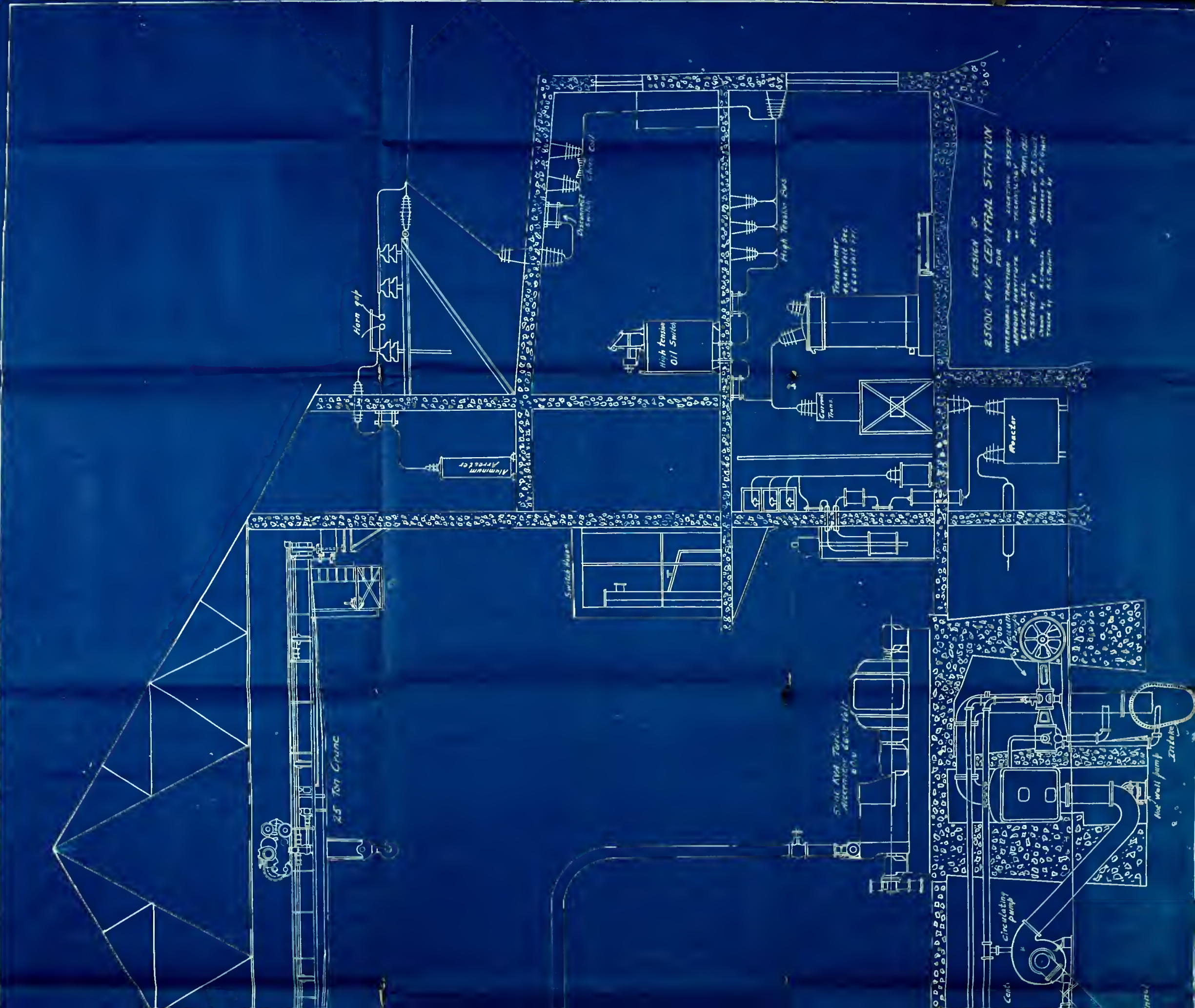

12" STEAM FEEDER
18" OPEN AIR EXHAUST
PUMP-TURBINE DRIVEN
BOILER FEED PUMP
0 KW. TURBINE DRIVEN EXCITER
INTAKE TUNNEL
150 KW MOTOR DRIVEN EXCITER
AUX. STEAM HEADER
MAIN STEAM HEADER
EXH. STEAM HEADER
CONDENSATE HEADER
BREECHING
FEED WATER HEATER
CHIMNEY - 10'-0"
24" WALL
18" WALL
500 HP B.&W. BOILER
HOT FEED WATER HEADER

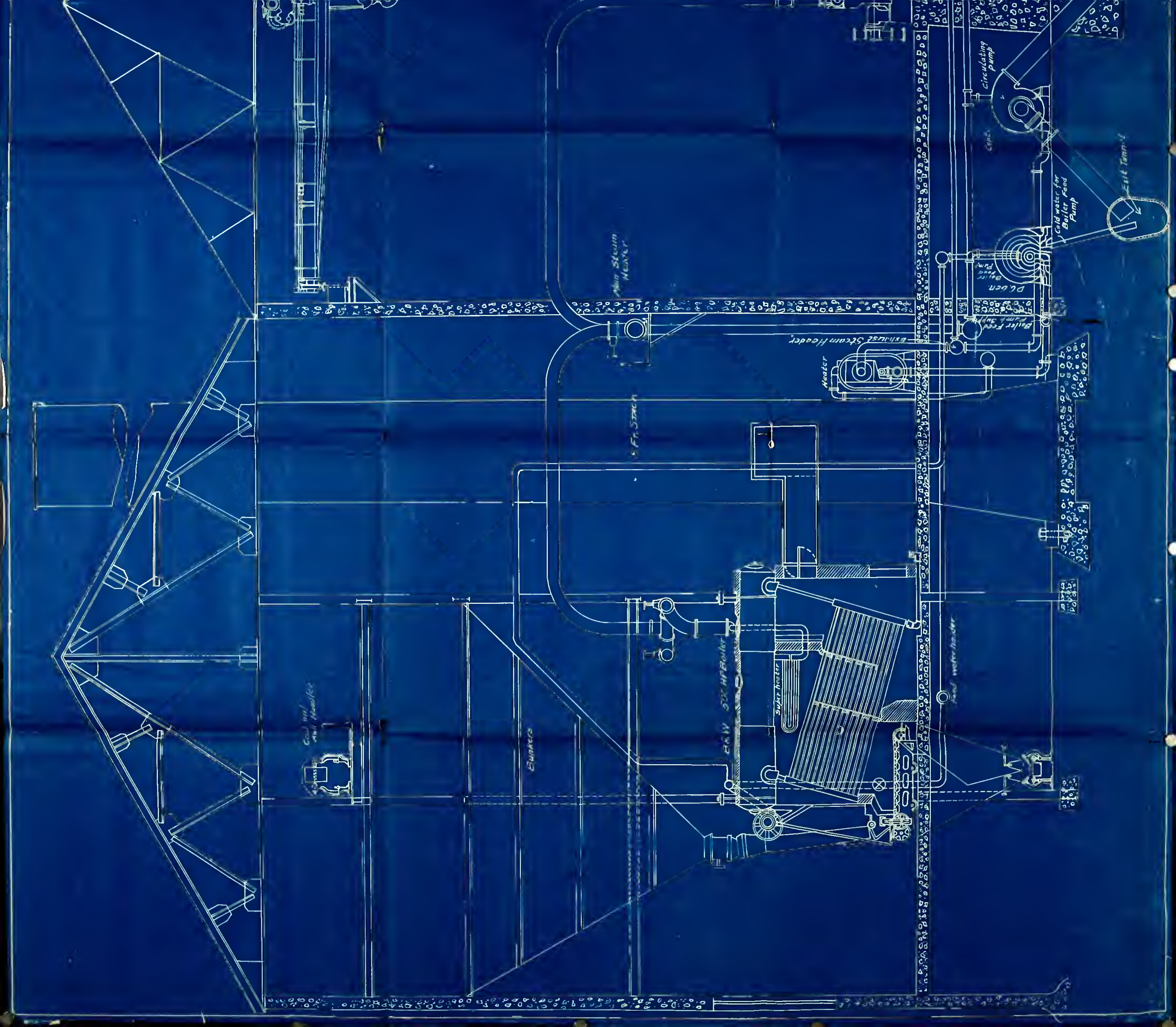


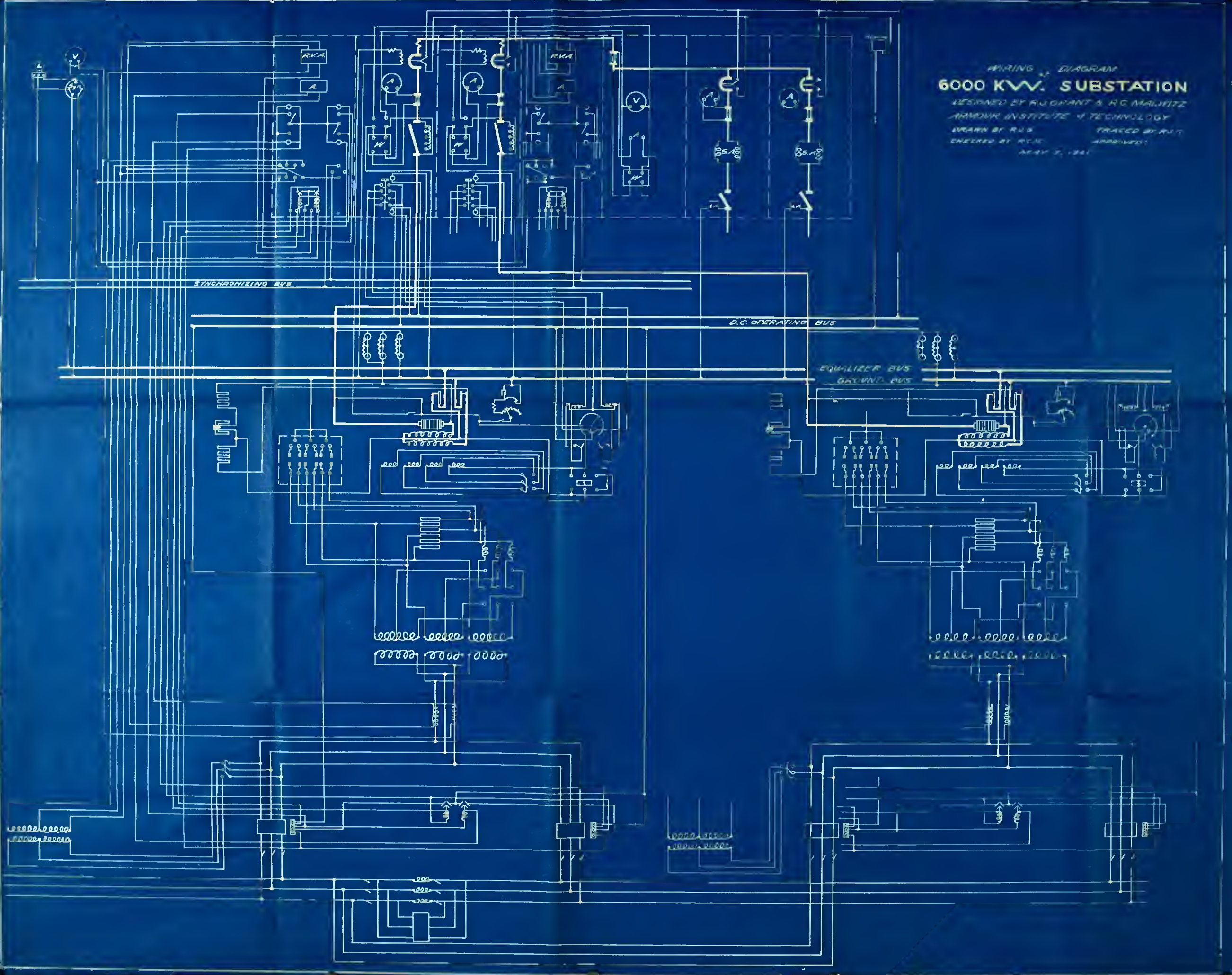
Wiring Diagram
of
CENTRAL STATION
25000 KVA & SUB-STATION
Designed by R.C. Malwitz + R.J. Grant
Drawn by R.C. Malwitz '21
Checked by
Date 1921
ARMOUR INSTITUTE of TECHNOLOGY


Freq Meter
Vm
Freq Meter
Vm
Line #2
Line #4
Ammeter
Line #1
Line #3
Operating Busses
Ground Bus
Synchronizing Busses
Volt Busses
Control Busses
Ground
Voltmeter
G
A
High Tension Fuses
High Frequency Arrester
Ground Detector
Choke Coils
Field Sw
Exciter Sw
Ground Bus Bars
1
2
3
To Field Bus
K2 Cri Sw arranged For interlocking
Closed when Sw is opened
Low Tension Busses
Closed when Sw is opened
Lightning Arrester
Clutch Motor Field
Exciting Busses


Amm
Line #1
Line #3
OPERATING BUSSES
Ground Bus
Synchronizing BUSSES
Volt BUSSES
CONTROL BUSSES
Ground
High Tension Busses
R
G
Voltmeter
P.F.M.
Ind. Watt
Field Ammeter
Ammeter
Ammeter
Ammeter
Motor
Turbine Gen
Motor


DESIGN OF
25000 KVA CENTRAL STATION
FOR
INTERURBAN TRACTION AND LIGHTING SYSTEM
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL.
DESIGNED BY
Drawn by
Traced by
Checked by
Approved by
Horn gap
Choke Coil
Disconnecting Switch
High Tension Bus
Transformer
High Tension Oil Switch
Current Trans.
Reactor
Aluminum Arrester
Switch House
25 Ton Crane
Hot well pump
Intake
Circulating pump

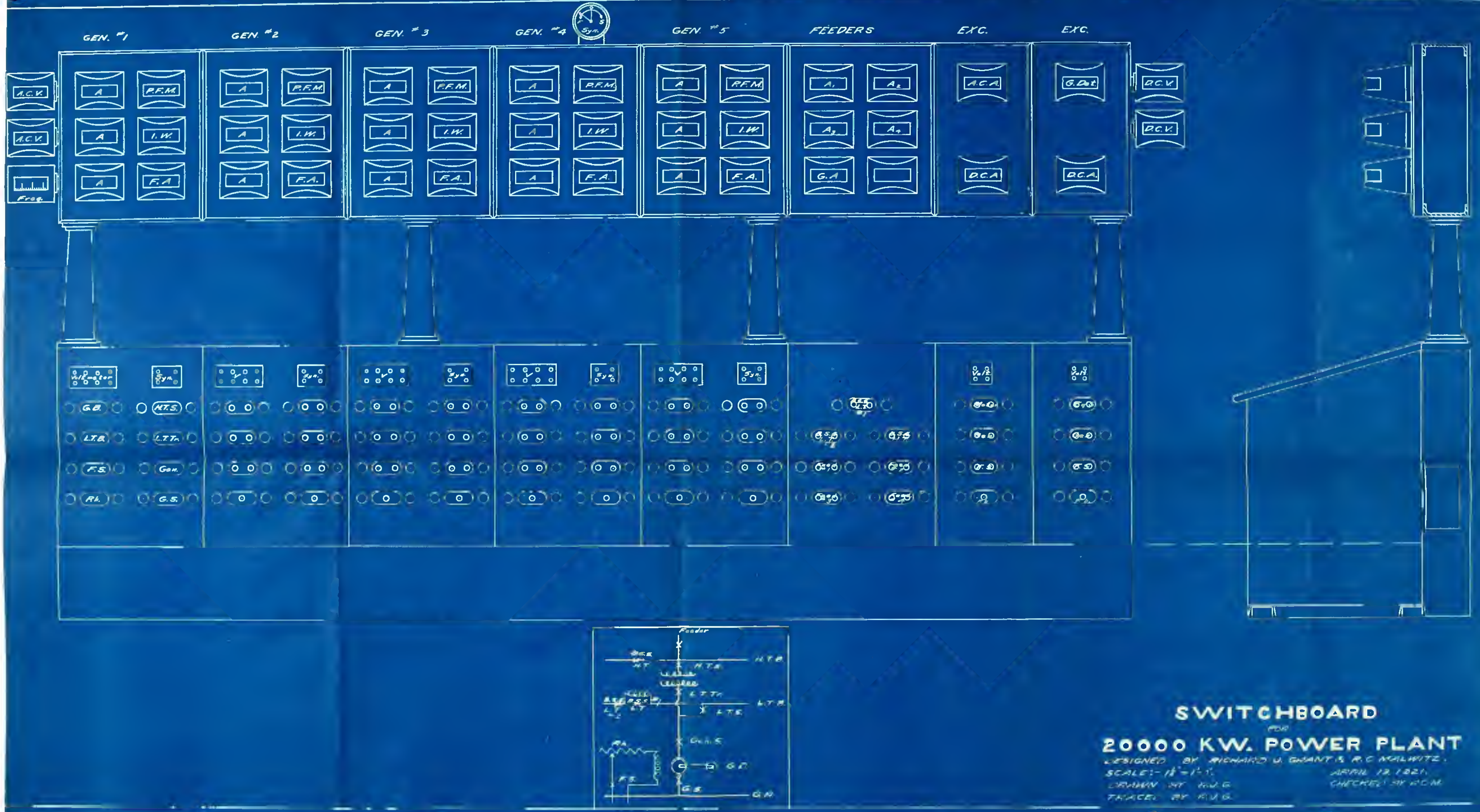

Circulating pump
Cond.
Exit Tunnel
Cold water for Boiler Feed Pump
Boiler Feed Pump
D.C. Gen.
Boiler Feed Pump Supply
Exhaust Steam Header
Heater
Main Steam Header
5 Ft. Stack
B&W 500 HP Boiler
Super heater
Feed water header
Bunkers
Coal and Ash Handler



WIRING OF DIAGRAM

6000 KW. SUBSTATION

DESIGNED BY R.J. GRANT & R.C. MALWITZ
ARMOUR INSTITUTE OF TECHNOLOGY
DRAWN BY R.J.G. TRACED BY R.J.G.
CHECKED BY R.C.M. APPROVED:
MAY 7, 1921



SWITCHBOARD

FOR

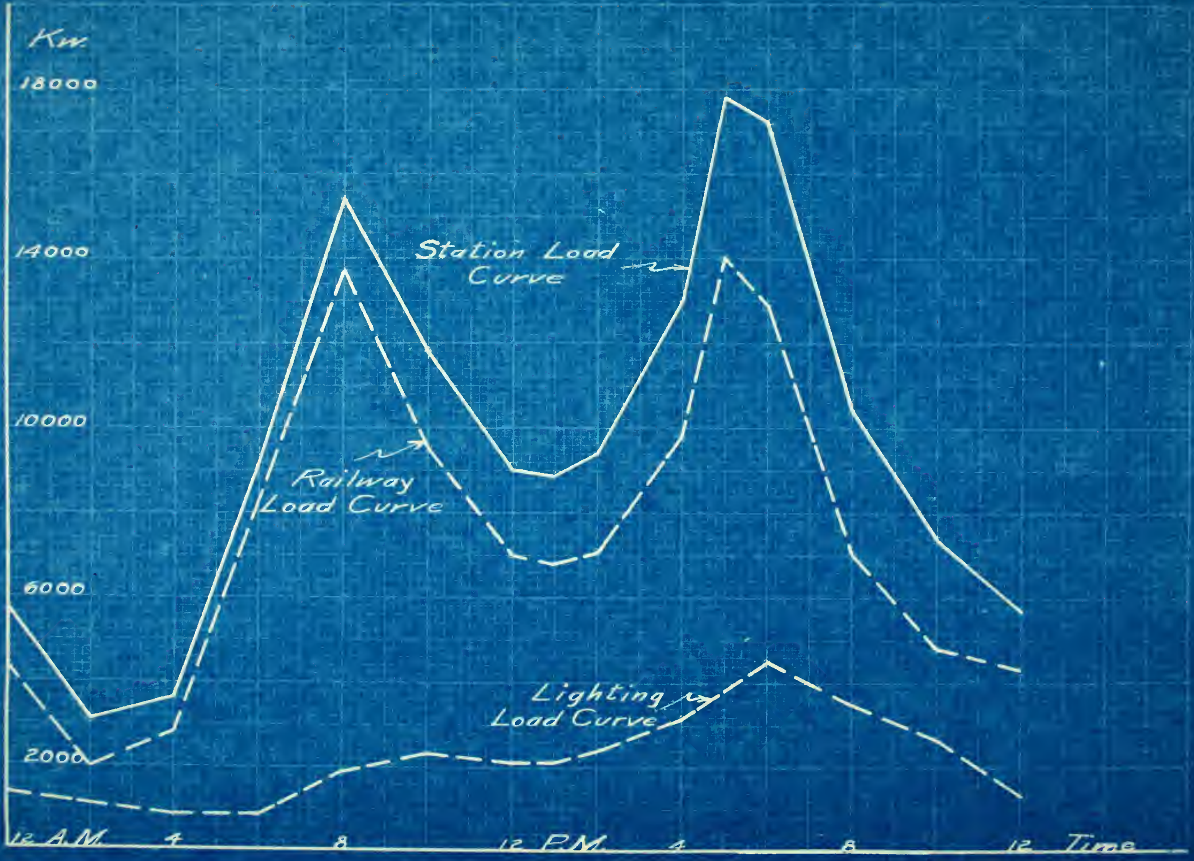
20000 KW. POWER PLANT

DESIGNED BY RICHARD U. GRANT & R. C. MALWITZ.

SCALE:- 1½" = 1'-1". APRIL 12, 1921.

DRAWN BY R.U.G. CHECKED BY R.C.M.

TRACED BY R.U.G.


Kw.
18000
14000
10000
6000
2000
12 A.M.
4
8
12 P.M.
4
8
12
Time
Station Load Curve
Railway Load Curve
Lighting Load Curve